REMOTE SENSING TOOLS TO STUDY OCEAN BIOGEOCHEMISTRY: THE STATE OF THE ART

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OCEAN BIOGEOCHEMISTRY: THE CARBON CYCLE

On a global basis, the ocean is a sink of atmospheric CO_2, although there are large regions which outgas to the atmosphere.

CO_2 is fixed by photosynthesis, or primary production (PP) into organic matter. This living matter also produces carbon dioxide through respiration. Small living or once-living stuff is often measured as particulate organic carbon (POC).

Photosynthesis on land and in the ocean is a major term of the global carbon budget through its influence on atmospheric CO_2. Oceanic and terrestrial PP are approximately equal, but land biomass is much larger.

New production is the oceanic PP fueled by nutrients originating outside the illuminated upper layer, in contrast to regenerated production which results from nutrients within the layer (Dugdale and Goering 1967).

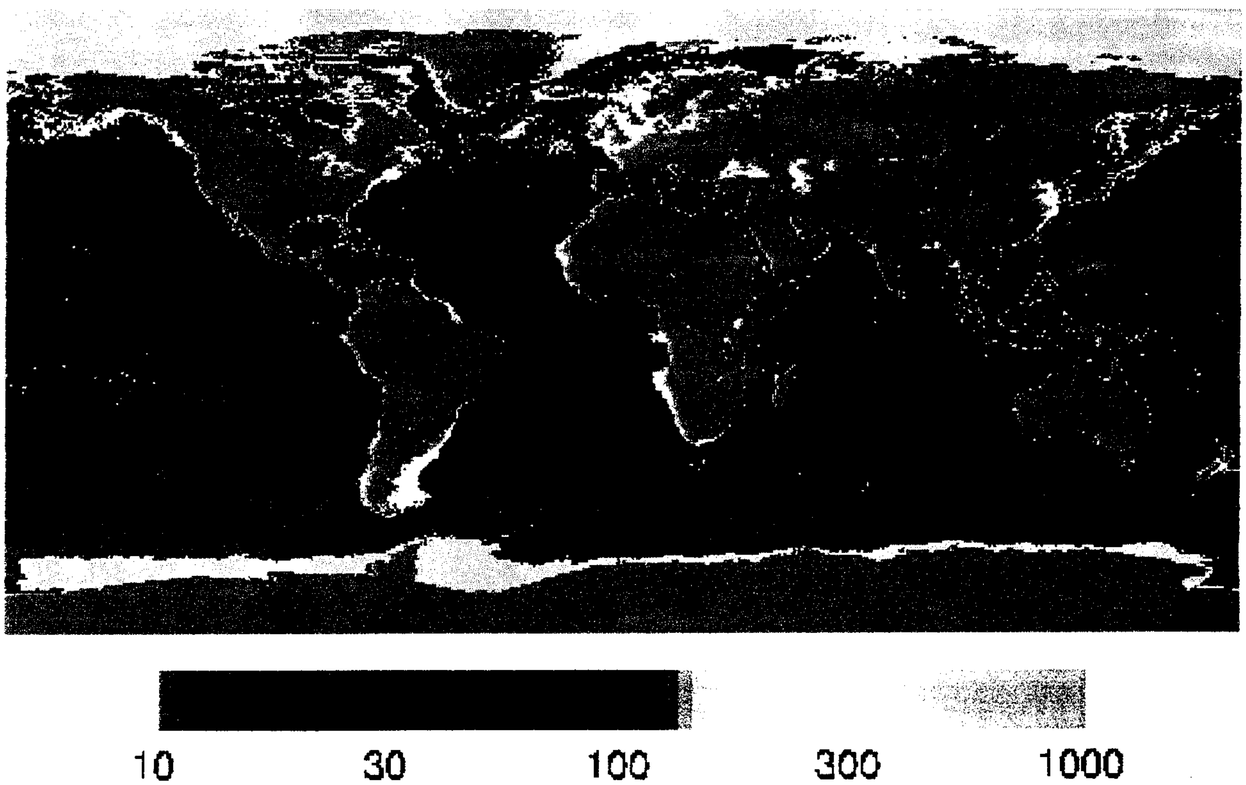
Steady state requires that the uptake of new nutrients be balanced by the export of carbon from the upper layer (Eppley and Peterson 1979).

Vertical export of carbon is related to sinking cells. The size and type of phytoplankter affect its sinking rate. Some cells present hard 'shells' of silica (diatoms) or calcite (coccolithophorids) which serve as ballast.

Sources of new nutrients are

- depth, via mixing or upwelling (Redfield ratios)
- horizontal advection (unimportant in open ocean)
- atmosphere
  - deposition.
  - uptake of atmospheric N_2. Only a small percentage of oceanic phytoplankters can do this they need iron and phosphorous, thus complicating the biogeochemical constraints on carbon cycling.

Dissolved organic carbon (DOC) also results from photosynthesis and decomposition. It can be converted to colored dissolved organic matter (CDOM) which in turn undergoes photochemical conversion. CDOM affects optical properties of ocean water and thus remote sensing of ocean color.

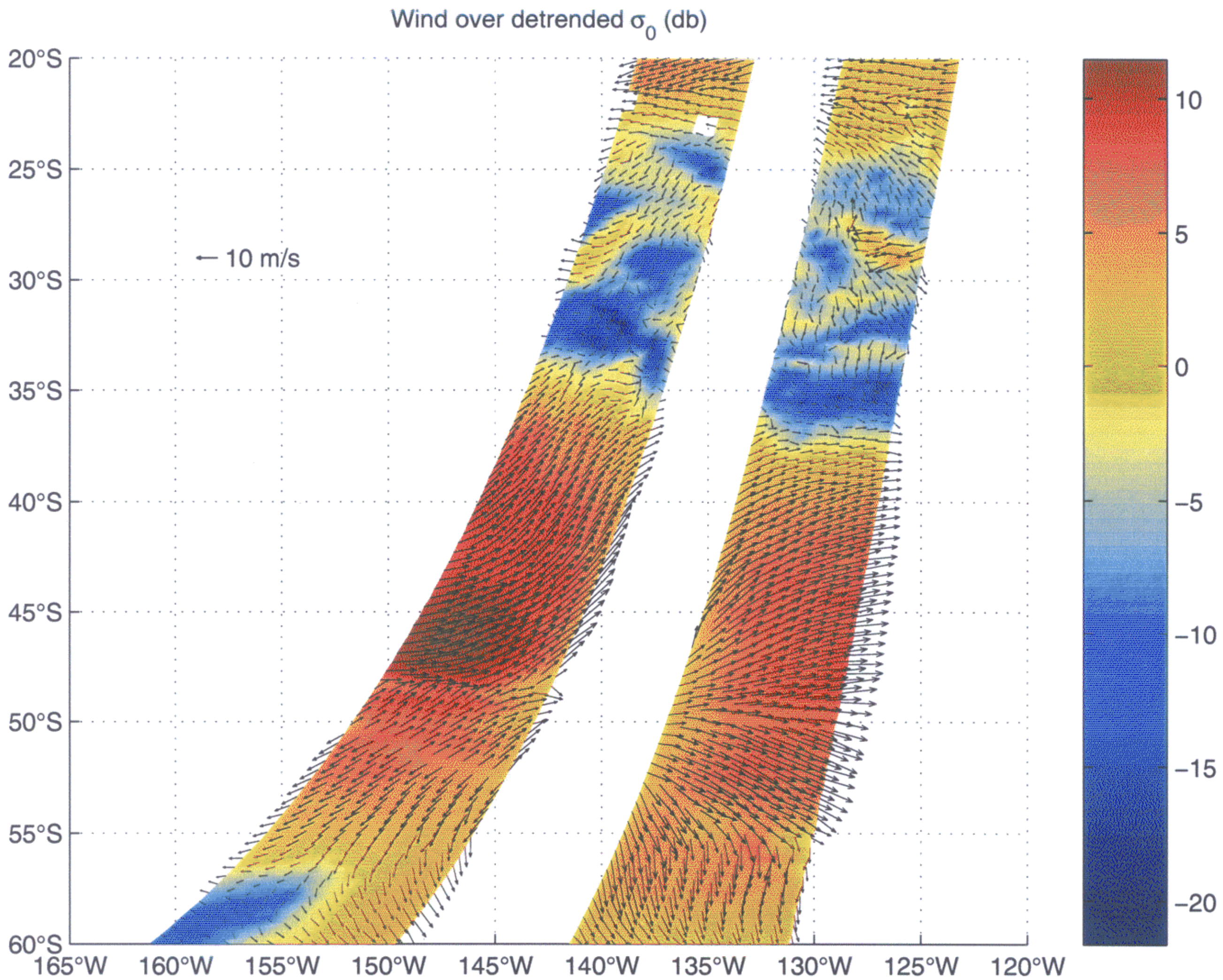


EXPORT PRODUCTION
Laws et al. 2001

The ratio of new to total production, the f-ratio, ranges from less than 0.1 to 0.6.

The impact of increased atmospheric CO_2 due to anthropogenic input cannot be understood without proper quantification of total and new production.

The detrended σ_0 for this example from NSCAT shows a more detailed spatial distribution than that of the wind.

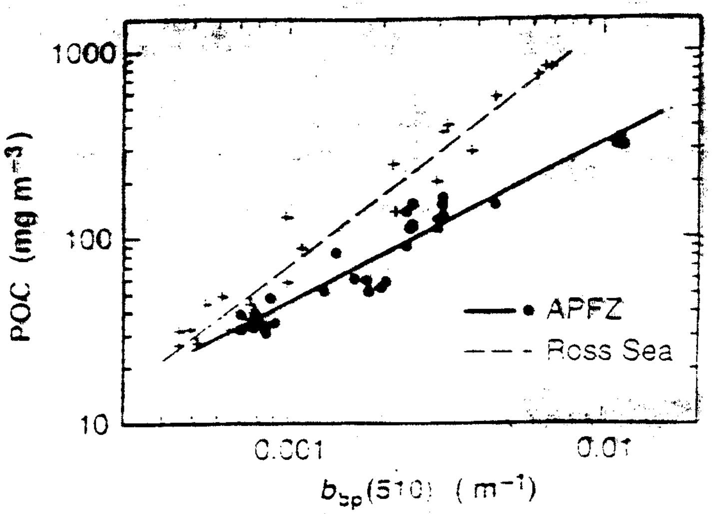


ESTIMATION OF POC FROM OCEAN COLOR

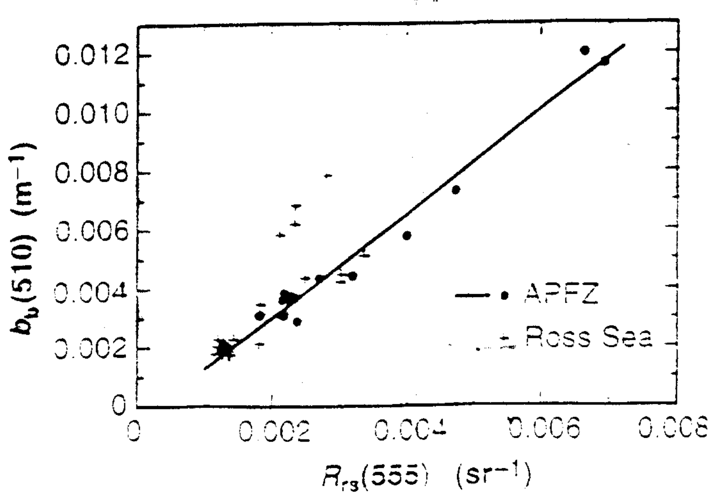
Stramski et al. *1999*

The estimation is based on two relations:

backscatter and POC concentration



remote-sensing reflectance and backscatter

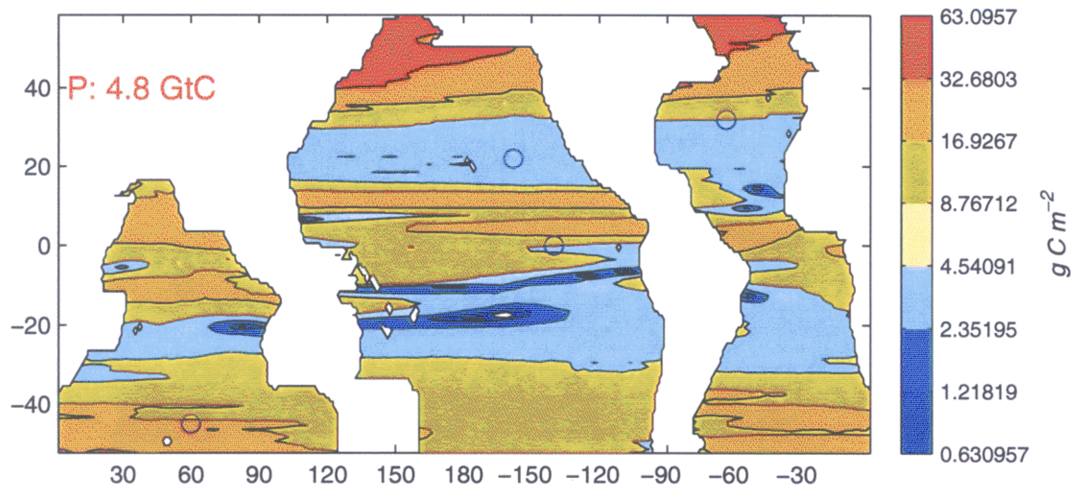


Site-specific relationships are probably necessary to ensure optimal estimate of POC on regional scales.

EXPORT PRODUCTION FROM HEAT STORAGE

Oceanic heat storage anomaly is derived from the sea surface height anomaly measured by the TOPEX /Poseidon altimeter (Polito et al., 2000).

Changes in the heat storage anomaly are inversely related to changes in nutrient storage, which tell us the net nutrient drawdown.



This approach is completely independent of chlorophyll concentration, primary production, or f-ratio, for which we have relatively little data.

Radar altimetry is not limited by cloud coverage and already presents a relatively long continuous time series (7 years).

QuikScat-BASED ESTIMATES OF EXCHANGE

Ideally the gas exchange coefficient should be characterized directly from the dynamics of the turbulent boundary layer or the near-surface diffusivity.

The capillary wave spectrum is a more direct indicator of gas exchange and can be estimated from the surface roughness, σ_0, measured by scatterometer.

QuickScat measures the surface roughness corresponding to $\simeq$ 4.5 cm capillary waves modulated by longer waves.

The total capillary wave contribution can be estimated from existing gravity-capillary and capillary wave spectra.

WHAT DO WE NEED TO KNOW?

Exchange of CO_2 between ocean and atmosphere:
pCO_2 of the ocean: SST, Salinity, [chl]
Gas exchange coefficient: wind, surface roughness

Photosynthesis: color, SST, irradiance

New or export production:
Supply of nitrogen:heat flux, precipitation
Nitrogen uptake: heat flux, heat storage, SST
f-ratio: SST, PP, $[NO_3]$, $[chl]$
Functional types: optical or compound remote sensing

Partitioning and conversion of carbon species: reflectance

Biological production of radiatively active gases: reflectance, irradiance

Atmospheric aerosol patterns: reflectance

Variability and unresolved process:
Eddies : (T/P)
Coastal processes : Geostationary platforms, multi-spectral reflectance

HOW DO WE USE SATELLITE OBSERVATIONS?

1. Derive relationship between *in situ* variable(s) of interest and remotely-sensed variable(s).

2. Apply relationship to maps of remotely-sensed variable(s).

Errors arise because the relationship

is poorly constrained.

does not hold everywhere or always.

Three examples of approaches which use remote sensing to derive something we want to know

Air-sea gas exchange coefficient from QuikScat (T/P) (Bogucki)

POC from ocean color (SeaWiFS) (Stramski)

New production from heat storage (T/P) (Carr)

WHAT CAN WE SENSE REMOTELY?

Great for spatio-temporal coverage and consistency of methodology.

Limited by what they can measure and depth of penetration and resolution.

- Sea surface temperature (SST): AVHRR, MODIS. TRMM sees through clouds; limited to $\pm 40^\circ$.
- (To be launched) Sea Surface Salinity
- Sea surface height (SSH): Topex/POSEIDON (T/P) and ERS1/2.
- Wind speed and direction : QuikScat (since June 1999), ERS2.
- Chlorophyll concentration : SeaWiFS, MODIS.

WHAT DO WE NEED TO KNOW?

Exchange of CO_2 between ocean and atmosphere:

- pCO_2 of the ocean: depends on circulation and biological activity

  - Current efforts relate pCO_2 to SST (Boutin *et al.* 1999, Lee *et al.* 1998), to surface salinity (Loukos *et al.* 2000) and chlorophyll concentration.

- Gas exchange coefficient: depends on turbulence of surface boundary layer

  - Usually parameterized as function of wind speed.

    Climatological wind fields are used (e.g. Takahashi *et al.* 1999). Scatterometers improve spatial and temporal resolution (Boutin and Etcheto 1997).

  - Estimates of capillary wave spectra from surface roughness from T/P (Frew *et al.* 2000) or from σ_0 from QScat (Bogucki *et al.* 2000).

Photosynthesis: Various algorithms exist relating ocean color to PP incorporating light and SST.

New or export production:

- Supply of nitrogen from heat flux (Peña *et al.* 1994) or precipitation.

- Nitrogen uptake from oxygen flux (Keeling, Garcia *et al.* 2000), altimeter heat storage (Carr *et al.* 2000) or models of SST changes as proxy of uptake (Dugdale *et al.* 1989).

- f-ratio generally function of $[NO_3]$, $[chl]$, PP, SST.

- Community structure using optical approaches or compound remote sensing.

CONCLUSIONS

- Satellite data are not perfect nor complete.

  Though the standard products of most sensors are of high quality (in most places), compound products (such as PP, new production, functional type, etc.) should not be taken at face value.

- Difficulties can become blessings, especially with the help of improved *in situ* measurements and clever approaches.

- Creative uses of existing satellite information, such as through inverse techniques, may provide unexpected boons.

- If you have an idea for a new sensor, tell people about it.